



MOKELUMNE WATERSHED AVOIDED COST ANALYSIS:

Why Sierra Fuel Treatments Make Economic Sense



Appendix C: GeoWEPP Modeling – Hillslope Erosion

C.1 Abstract

Fuel reduction treatments are effective in modifying fire behavior and reducing fire severity. However, the costs associated with fuel reduction treatments often limit their spatial application. A need exists for tools and datasets that can be used by land managers to prioritize the spatial application of treatments in order to justify their costs in a time of decreasing budgets. Fuel treatments are commonly used to provide some protection to sensitive habitats and at the Wildland-Urban Interface (WUI), but they can also be undertaken to mitigate the effects of postfire erosion on water resources. Our goal is to assist land managers and decision-makers in the Mokelumne watershed by predicting the effects of fuel reduction treatments on hillslope erosion. Burn severity was modeled for the Upper Mokelumne watershed before and after fuel reduction treatments using FlamMap. GeoWEPP with Disturbed WEPP parameters was then used to predict postfire hillslope erosion both before and after treatments; runs were also carried out to model erosion from the current landcover and the treatments. After treatments (Chapter 2) were applied in the model, the mean annual reduction in first year postfire erosion rates in the treated portion of the watershed was 20 Mg/yr¹ha (Megagrams per hectare per year; one Megagram = 2205 pounds), a reduction of 62%. If the reduction in the probability of fire occurrence and the effects of treatments are considered together, then the treatments are predicted to significantly impact long-term (century scale) erosion rates by lowering “average annual” erosion rates by 19%.

C.2 Introduction

Increased fuel loads from decades of fire suppression (Agee 1993; Keane *et al.* 2002) and climate change (Flannigan *et al.* 2000; Westerling *et al.* 2006) are increasing the risks of large, high severity wildfires in Western forests and shrublands. These high severity fires in turn increase the risk of flash floods and surface erosion (Forrest and Harding 1994; Neary *et al.* 2005). Increased postfire erosion rates can severely degrade water quality and reduce reservoir storage capacity (Tiedemann *et al.* 1979; Moody and Martin 2001; Neary *et al.*, 2005). In response to these risks, the land managers responsible for protecting forestlands and watersheds, especially those that provide water to cities and towns, want to mitigate the effects of wildfire on water resources through the use of fuel reduction treatments. Fuel reduction treatments, such as thinning and prescribed burning, have been shown to be effective in modifying fire behavior and fire severity (Cochrane *et al.*, 2012), which can reduce threats to ecosystem services. The costs associated with these treatments, however, limit their application (GAO 1999; Sampson *et al.* 2000; GAO 2007). Therefore we are seeking to quantify the benefits of fuel reduction on postfire erosion rates in the Mokelumne watershed and to assist in the spatial prioritization of fuel reduction applications.

C.3 Modeling approach

A coupling of two different models was needed to predict the effects of fuel reduction treatments on hillslope erosion in the Mokelumne watershed. The first model, FlamMap, was used to predict burn severity both before and after proposed fuel reduction treatments (Appendix A). The WEPP model then used the burn severity predictions from FlamMap to predict hillslope erosion following wildfire both before and after treatments. An added benefit of our modeling approach is that we were able to use our predictions of postfire erosion for current conditions (before treatments) to help plan where to place fuel treatments within the watershed. WEPP runs were carried out to model hillslope erosion rates in the watershed without a wildfire. Additional runs were carried out to model erosion that would result from disturbances to the forest from the application of the proposed treatments.

C.3.1 FlamMap

FlamMap is a spatial fire behavior model that uses land cover, topography, and fuel characteristics data from the LANDFIRE database, along with fuel moisture and weather data (Finney 2006). Resulting fire behavior predictions are pixel based and include fireline intensity (kW/m), heat per unit area (kJ/m²), and flame length (m). Probabilities of fire occurrence can also be calculated using long term weather data. We used a cross walk table (Table C.1) between flame length and burn severity to estimate postfire soil burn severity and ground cover. The cross walk was determined within our group based on previous studies combined with the experience of the participants in the analysis. FlamMap was first used to predict burn severity for current conditions in the Mokelumne watershed. Fuel reduction treatments alter vegetation canopy and this impacts fire behavior, therefore FlamMap was run a second time to predict burn severity after proposed fuel reduction treatments.

Table C.1: Crosswalk table for converting FlamMap flame length to burn severity

burn severity prediction	Flame Length (ft)			
	0	0-4	4-8	8+
	Unburned	Low	Moderate	High

C.3.2 WEPP

WEPP (Water Erosion Prediction Project) is a process-based model that predicts runoff and sediment yields from planar hillslopes and small, unchannelized watersheds (Flanagan and Nearing 1995). The surface hydrology component of the WEPP model uses climate, soils, topography, and vegetation input files to predict infiltration, runoff volume, and peak discharge for each simulated storm. WEPP then uses these inputs and predictions to calculate rill and interrill erosion, as well as sediment deposition (Flanagan and Nearing 1995). Disturbed WEPP (Elliot 2004) is an online interface for WEPP designed to facilitate the use of WEPP in forested areas. Disturbed WEPP can simulate different forest conditions and management scenarios, including the effects of fuel treatments, and the model has been used to predict postfire erosion in forested areas (Soto and Diaz-Fierros 1998; Larsen and MacDonald 2007; Spigel and Robichaud 2007). The need to predict postfire erosion rates across the entire Upper Mokelumne watershed necessitated the use of the Geo-spatial interface for the Water Erosion Prediction Project (GeoWEPP) (Renschler 2003).

GeoWEPP facilitates the use of WEPP across large areas by converting GIS data into WEPP inputs, running WEPP, and then compiling the results into a spatial map (Renschler 2003). The various plant/management and soil input files developed for burned areas and used in the Disturbed WEPP interface were used to create the different sets of input parameters needed by the underlying WEPP model.

C.3.2.1 Development and compilation of input data

Prior to preparing the model, the authors visited the watershed to collect data at various elevations and forest conditions. These findings were then compared to the data compiled from other sources to ensure accuracy, with adjustments made as necessary. For the spatial WEPP modeling, the Upper Mokelumne watershed was divided into 305 sub-watersheds using a Digital Elevation Model (DEM) and ESRI watershed tools. Sub-watersheds were used to create smaller raster inputs (DEM, soil, landcover) for batch files. These batch files were then modeled in a batched version of GeoWEPP (Miller et al. 2011). In the cases where the sub-watersheds contained more than one drainage outlet or the model failed to run, the sub-watersheds were rerun using GeoWEPP for ArcGis 9.3. The resulting erosion prediction maps from the batch runs were then merged into the final erosion maps.

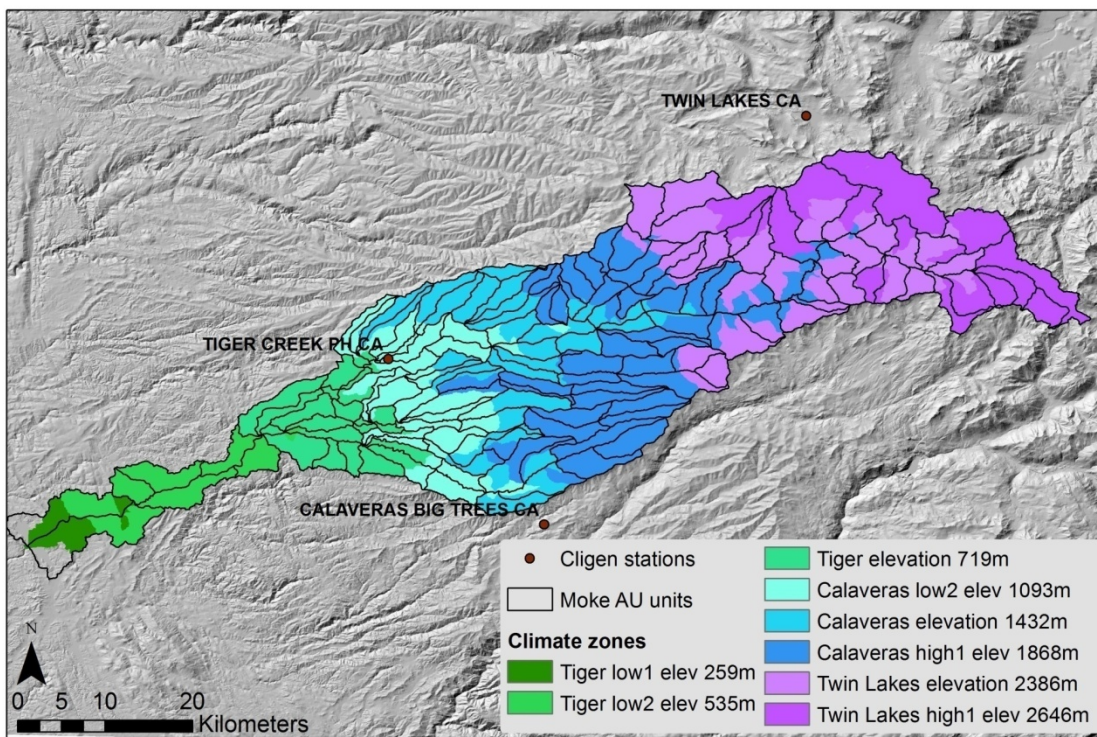
C.3.2.2 Climate data

A key model input for predicting erosion rates is climate data; WEPP uses a stochastic weather generator called Cligen (Nicks et al. 2005) to generate the climate parameters needed to model run-off and erosion (mean daily precipitation, minimum and maximum daily temperatures, dew point, mean daily solar radiation, and mean daily wind speed and direction). Cligen has a database of more than 2,600 climate stations within the United States. The U.S. Forest Service has improved these climate parameters with Rock:Clime, an interface to Cligen which interpolates climate parameters between stations (Elliot et al. 1999; Scheele et al. 2001). This interpolation is particularly important in mountainous areas like the Mokelumne watershed because of the large changes in climate conditions that occur with changes in elevation, as well as the paucity of climate stations in these areas. The interpolation procedure in Rock:Clime modifies the data for a selected climate station based on elevation and PRISM data (Parameter-elevation Regressions on Independent Slopes Model). PRISM uses elevations, point sources of climatic data, and other spatial data sets to generate grids of climate data at a resolution of 4 km (Daly et al., 2004).

Three Cligen stations are located within or near the Mokelumne watershed and these stations (Twin Lakes, Calaveras Big Tree, and Tiger Creek) were used to generate an additional five climates with the Rock:Clime interface. The additional climates were generated to account for the impacts of elevation changes in the watershed (Table C.2). Each climate file was created to contain 50 years of daily stochastically generated weather data. The average elevations of the initial WEPP sub-watersheds were then used to select the appropriate climate file (Figure C.1) for each sub-watershed.

Table C.2: Stochastically generated climate files for the Mokelumne watershed

Elevation Ranges	Climate Station	elevation	avg. annual precip
100m – 300m	Tiger low Rock:Clim Prism:	259 m	799 mm
300m – 600m	Tiger low2 Rock:Clim Prism	535 m	951 mm
600m – 900m	Tiger Creek station	719 m	1176 mm
900m – 1200m	Calaveras low Rock:Clim Prism	1093 m	1138 mm
1200m – 1500m	Calaveras Big Trees station	1432 m	1383 mm
1500m – 2000m	Calaveras Big Trees high Rock:Clim Prism	1868 m	1336 mm
2000m – 2400m	Twin Lakes station	2386 m	1249 mm
2400m +	Twin Lakes high Rock:Clim Prism	2646 m	1438 mm

Figure C.1: Distribution of climate forecasts within the Mokelumne watershed

C.3.2.3 Land cover and plant/management input files for WEPP

Landcover data were obtained from the LANDFIRE Project, a joint venture between the U.S. Department of Agriculture Forest Service and the U.S. Department of the Interior. LANDFIRE data layers include information on potential and existing vegetation, fire regimes, fire risk, surface and canopy fuels, topography, and disturbances (Rollins, 2009). For this analysis, we used LANDFIRE data updated based on field observations for the fire modeling runs. In addition to making the process more efficient through sharing data, this ensured consistency across the modeling efforts. We then reclassified the Existing Vegetation data layer into Disturbed WEPP cover types in order to model background erosion rates from the Mokelumne watershed without fire. For modeling postfire conditions, the FlamMap burn severity maps from before and after fuel

reduction treatments were used to reclassify landcover into low, moderate, and high burn severity classes (based on Table C.1). In order to model the effects of the fuel reduction treatments, we used the map of the proposed treatments developed for this analysis.

C.3.2.4 Soils data

For the WEPP modeling, we used LANDFIRE soil layers that were derived from STATSGO (STaTe Soil GeOgraphic) data (USDA 1991). This dataset included: maximum soil depth; percent rock fragments (> 2.0 mm); percent sand; percent silt; and percent clay. The percent sand, silt and clay layers were used to classify each soil pixel into one of the four soil texture classes represented in Disturbed WEPP (sandy loam, loam, silt loam, and clay loam). Disturbed WEPP input parameters (e.g., effective hydraulic conductivity, soil albedo, and rill erodibility) specific to each soil texture class were then used in the modeling (Elliot *et al.* 2000). Soil parameters also vary according to predicted burn severity and upon the type of vegetation.

C.3.2.5 Topographic data, watershed delineation, and processing

The DEM was downloaded from the National Elevation Dataset at a 30m resolution (Gesch *et al.*, 2002; Gesch, 2007). GeoWEPP utilizes TOPAZ, Topographic Parameterization (Garbrecht and Martz 1999), in order to delineate watersheds and create the slope parameter files needed to run WEPP. Required input parameters for TOPAZ include the critical source area (CSA) and minimum source channel length (MSCL). We used the default GeoWEPP settings for these variables, 5 ha for CSA and 100 m for MSCL, which resulted in a mean hillslope size of about 6 ha.

C.3.3 Results

Erosion from hillslopes in the Mokelumne watershed was modeled and mapped under four distinct conditions. 1) Current vegetation conditions in the absence of fire; 2) after a fire assuming current fuel conditions; 3) after the fuel treatments and no fire; 4) and finally, fuel treatment conditions after a fire. When interpreting the results it is important to note that WEPP predicts one potential component of erosion: small soil constituents, 2 millimeters or smaller in size. The first condition determined background erosion rates without fire under the current vegetation conditions. Average erosion in the unburned basin was $0.67 \text{ Mg/yr}^1\text{ha}$ for the entire basin and $0.4 \text{ Mg/yr}^1\text{ha}$ in the lower treated section. Forested hillslopes typically did not generate significant erosion, but the steep, barren rocky slopes in the upper portions of the basin were highly erosive. The next run used the FlamMap predictions of burn severity under the current vegetation conditions to predict postfire erosion (Figure C.2). Average first year postfire hillslope erosion in the Mokelumne watershed was $32 \text{ Mg/yr}^1\text{ha}$, much higher, more than 30 times, the unburned conditions. The mapped postfire erosion predictions were used by our committees to plan and prioritize a hypothetical fuel reduction treatment strategy within the basin. The application of these treatments, which included prescribed fire, biomass removal, and thinning, would also impact erosion rates within the watershed, so the effects of these treatments were modeled in our third run. Fuel treatments were only planned in the lower portions of the watershed and the average predicted erosion rate from these treatments was $0.69 \text{ Mg/yr}^1\text{ha}$, an average increase of $0.02 \text{ Mg/yr}^1\text{ha}$ over no treatments. Canopy cover would change as a result of the treatments and the effect this would have on burn severity was modeled in FlamMap, the

results of which were used to model first year postfire erosion. For the condition of modeled implementation of treatments following fire, the average postfire erosion rate for the whole watershed was 26 Mg/yr¹ha, or 6 Mg/yr¹ha less than the average postfire erosion rates before treatments. In the second year postfire, erosion rates for both the current conditions and treated conditions are predicted to drop to only 10% of their first year postfire values, and return to pre-fire levels in year three postfire. A summary of erosion results and statistics for the entire watershed is found in Table C.3. If only the treated portions of the basin are summarized; the reduction in postfire erosion between the current conditions and treated runs is even greater: 20 Mg/yr¹ha (Table C.4).

Figure C.2: Predicted erosion for the first year postfire based on current vegetation

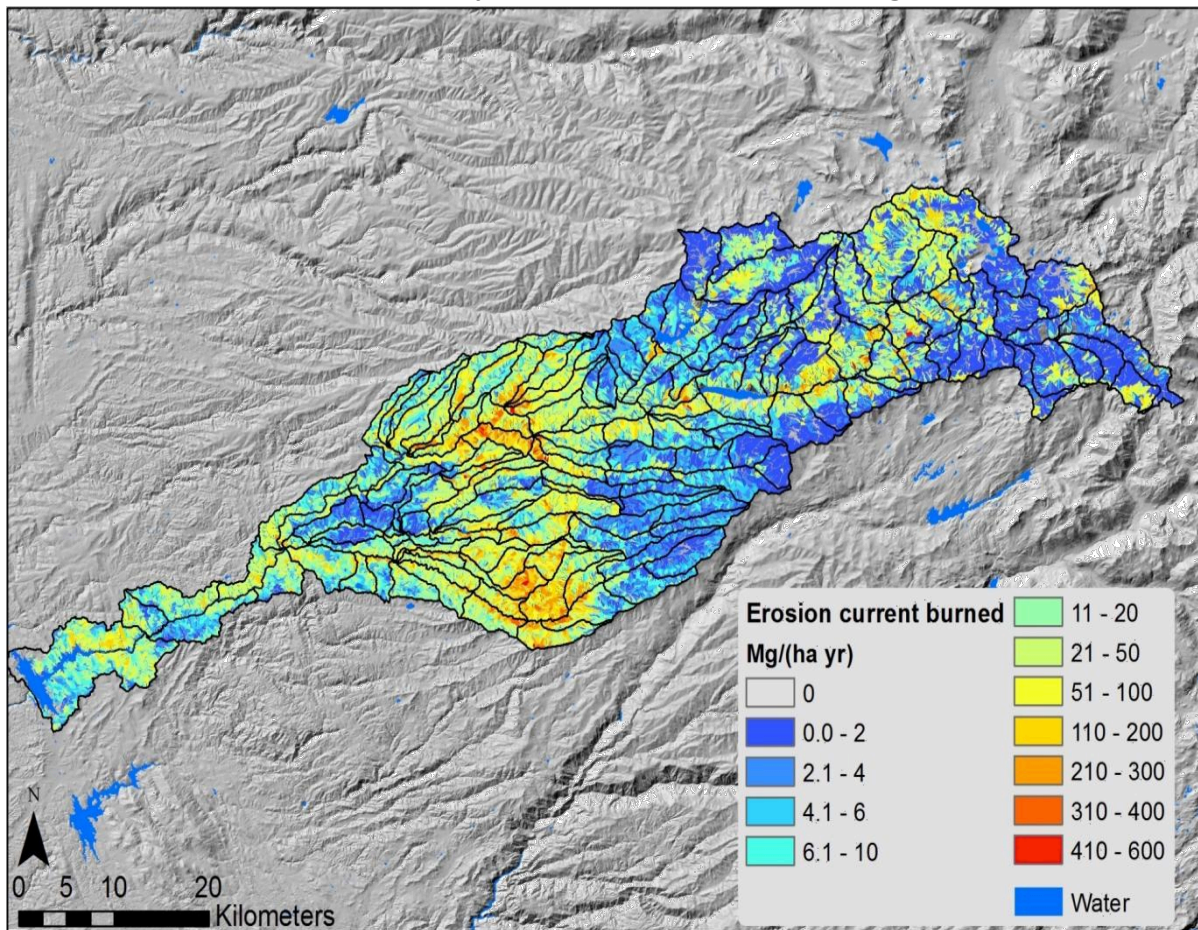


Table C.3: Summary of the results from four model runs for the entire Mokelumne watershed

	Current Condition	Fire Following Current Condition	Treatment Effects	Fire Following Treatment
Average Erosion in Basin	0.67 Mg/ha	32 Mg/ha in year 1	0.69 Mg/ha	26 Mg/ha in year 1
Range	0 – 84 Mg/ha	0 – 566 Mg/ha	0 – 84 Mg/ha	0 – 535 Mg/ha
Standard Dev	3.0 Mg/ha	55 mg/ha	2.5 Mg/ha	44 Mg/ha

Table C.4: Summary of results from four model runs for only the affected areas

	Current Condition	Fire Following Current Condition	Treatment Effects	Fire Following Treatment
Average Erosion in Basin	0.40 Mg/ha	46 Mg/ha in year 1	0.69 Mg/ha	26 Mg/ha in year 1
Range	0 – 84 Mg/ha	0 – 566 Mg/ha	0 – 84 Mg/ha	0 – 535 Mg/ha
Standard Dev	2.5 Mg/ha	69 mg/ha	2.5 Mg/ha	36 Mg/ha

Our predictions of both burn severity and postfire erosion rates are comparable to field and satellite derived measurements collected in or near the basin. Model validation of postfire erosion is very difficult given the high variability in erosion rates and uncertainties involved with predicting future fire effects and climate scenarios. However, the ratio of high, moderate, and low burn severity from the FlamMap derived predictions for postfire burn severity were consistent with a satellite-derived map of burn severity from the Power Fire that burned within the Mokelumne watershed in 2004. Field measurements of postfire erosion rates from the nearby Cannon Fire ranged from 2.5-15 Mg/yr¹ha (Robichaud et al. 2008) and the Cannon Fire site is drier than the Mokelumne watershed, with a mean annual precipitation of only 658 mm compared to the range of 799-1438 mm expected in the Mokelumne watershed. While this comparison does not validate our modeling, it does demonstrate our results are reasonable.

C.3.4 Frequency of burning

The fire behavior modelers also provided spatial predictions of fire probability for both current conditions and after the application of fuel reduction treatments. One of the benefits of fuel reduction treatments is a decrease in fire probability due to changes in fuels and canopy, note that probability of fire in a given year is fairly low. Figure C.3 is a comparison between (A) the first year postfire erosion under current conditions multiplied by current burn probability and (B) first year postfire erosion following treatments multiplied by burn probability after treatments. The negative areas on the map represent regions which are modeled to have a slightly higher burn severity after treatments, but overall the modeled treatments are predicted to decrease burn severity and postfire erosion. The average reduction in postfire erosion for the entire basin due to fire between the current conditions and post treatment was 0.05 Mg/yr¹ha. This metric, however, does not allow us to examine the effects of the treatments on erosion rates in the absence of fire. In order to consider all four model runs we needed to look at long term (century scale) “average annual” erosion rates.

To develop predictions for long term “average annual” erosion rates in the watershed we needed to account for erosion in both fire and non-fire years, as well as the effects of treatments on erosion rates and burn probabilities. Under current conditions, the long term hillslope erosion rate (Avg. Erosion_{cc}) can be represented by Equation 1. If we assume that the effects of the fuel reduction treatments last for 25 years, then Equation 2 could represent long term erosion rates (Avg. Erosion_{tr}) with regular fuel reduction treatments.

$$\text{Avg. Erosion}_{cc} = E_{cc_fire} * bp_{cc_fire} + (1 - bp_{cc_fire}) * E_{nf} \quad (\text{Eq 1})$$

$$\text{Avg. Erosion}_{tr} = E_{tr_fire} * bp_{tr_fire} + (1 - bp_{tr_fire}) * (24 * E_{nf} + E_{tr})/25 \quad (\text{Eq 2})$$

Where:

E_{cc_fire} is the mapped postfire erosion rates for current conditions.

E_{tr_fire} is the mapped postfire erosion rates following fuel treatments.

E_{tr} is the mapped erosion rates due to the effects of the fuel treatments.

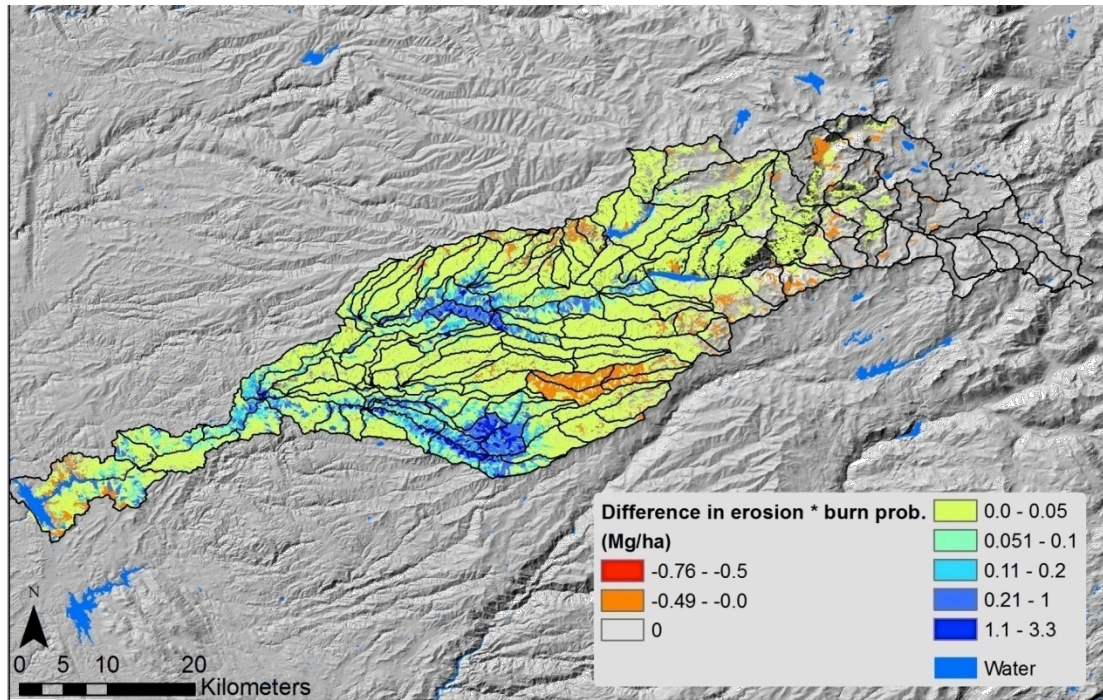
E_{nf} is mapped erosion rates for current conditions in the absence of fire.

bp_{cc_fire} is the mapped probability of fire under current conditions.

bp_{tr_fire} is the mapped probability of fire following fuel treatments.

These equations were used in conjunction with our four model runs to develop long term “average annual” erosion rates for the treated portions of the watershed with and without fuel reduction treatments every twenty five years. Model results for long term average erosion rates for current conditions were 0.64 Mg/yr¹ha, compared to 0.52 Mg/yr¹ha if the designated treatment area is in fact treated as modeled. Our predictions indicate that regular treatments will significantly reduce long term overall erosion rates by lowering “average annual” erosion rates by 19%.

Figure C.3. Difference between postfire erosion predictions for current conditions x burn probability for current conditions and posttreatment x burn probability posttreatment



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Disclaimer

This report is rich in data and analyses and may help support planning processes in the watershed. The data and analyses were primarily funded with public resources and are therefore available for others to use with appropriate referencing of the sources. This analysis is not intended to be a planning document.

The report includes a section on cultural heritage to acknowledge the inherent value of these resources, while also recognizing the difficulty of placing a monetary value on them. This work honors the value of Native American cultural or sacred sites, or disassociated collected or archived artifacts. This work does not intend to cause direct or indirect disturbance to any cultural resources.

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